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Portland Cement with Low Alkali Content.

A METHOD of reducing the alkali content of Portland cement clinker by means of prolonged heating, as practised by the Yosemite Portland Cement Corporation of California, is described by Messrs. H. McLarmour, E. L. McMaster, and Wm. Jacques as follows :

The hot kiln clinker discharges directly into a converted rotary cooler, brick lined throughout, with a dust chamber and stack at the discharge end and a burner at the feed end. The discharged clinker is reheated in the treater to substantially clinkering temperature. The flame, the effluent gases, and the reheated clinker travel in the same direction ; this permits greater flexibility for controlling the length of time of the clinker at a desirable temperature in a reducing atmosphere. Reheating in a reducing atmosphere is satisfactory in prolonging the life of lining and expelling alkalis, due to the characteristics of a reducing flame which is non-impinging.

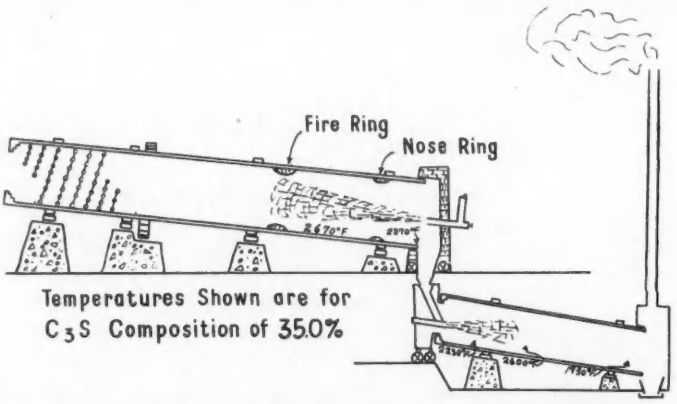
The wet process gas-fired kiln is 10 ft. diameter by 240 ft. long, with natural draught. It is equipped with chains, and has a maximum production of 260 tons per day. The treater is a converted rotary cooler, 7 ft. by 95 ft., bricked throughout, with natural draught. The fuel is oil or natural gas, giving a total of 2,400,000 B.T.U. per ton. The raw materials consist of " high " and " low " limestone, both diluted with the same interlaid shale, the amount of which determines whether the limestone is of " high " or " low " purity. The alkali is associated with the shale, since the high-purity limestone has little or no alkali content while the low-purity limestone is high in alkali. The alkali content of the quarry materials is estimated (assuming no loss in the kiln) to produce clinker in excess of 1 per cent. alkali as Na_2O for normal slurry.

The substitution of a siliceous material low in alkali to replace the " low " limestone was not practicable. It was found that 36 lb. of calcium chloride per barrel of slurry was effective in lowering the alkali content of the clinker to a

desirable minimum, but the cost of the material and handling as well as other considerations made this method undesirable. Therefore the removal of the alkali had to be considered.

The current specifications for low-heat cement require that the C_3S be not greater than 35 per cent., and the C_3A be not greater than 5 per cent. This meant that iron must be added in some form. In the burning process these changes dictated lower clinkering temperatures, which in turn were conducive to higher alkali content in the clinker. The analysis of the raw materials showed that the alkali content ranged from 1.2 per cent. to 0.8 per cent. (ignited basis) as Na_2O from " low " limestone to " high " limestone.

Eight trial " burns " of varying composition were made. The hot clinker was passed directly through the treater for reheating. Analyses of the slurry, kiln clinker, and treated clinker were made for K_2O, Na_2O, and compound composition. The two trial burns for the extreme compositions (15 per cent. and 71 per cent.



C_3S) extended over a period of 48 hours each. For the other compositions much longer burning periods were maintained, during which a desirable quality clinker was maintained with a fair average kiln operating condition. For this reason the alkali results were probably somewhat higher than would have been the case if a short trial had been made with every effort to produce ideal clinker. Samples of the raw mix, kiln clinker, and treater clinker were taken continuously during the trials. Table I shows the C_3S, K_2O, Na_2O, and total alkalis as Na_2O (ignited basis) contents of six of these mixes.

The heat treating temperature of the eight burns varied somewhat with the clinker design. In general the burning and treating temperatures of a clinker of 35 per cent. C_3S were very close to the following:

Kiln burning temperature	2,670 deg. F.
Kiln discharge clinker	2,370 deg. F.
Treater clinkering feed section	2,230 deg. F.
Treater reheating zone	2,600 deg. F.
Treater discharge section	1,930 deg. F.

In maintaining these temperatures in the treater it was necessary to have a heat input of approximately 2,280,000 B.T.U. per ton.

TABLE I.

C_3S	K_2O	Na_2O	Total as Na_2O
15·0 per cent. ..	0·906	0·590	1·19
27·0 ,, ..	0·909	0·513	1·10
32·5 ,, ..	0·899	0·488	1·08
50·6 ,, ..	0·745	0·579	1·07
56·5 ,, ..	0·911	0·397	0·966
71·1 ,, ..	0·698	0·430	0·889

The C_3S, K_2O, Na_2O, and total alkalis calculated as Na_2O in the clinker of each of the eight mixes are shown in Table II.

TABLE II.

C_3S	K_2O	Na_2O	Total as Na_2O
15·0 per cent. ..	0·682	0·441	0·890
27·0 ,, ..	0·543	0·351	0·708
32·4 ,, ..	0·482	0·399	0·716
32·5 ,, ..	0·572	0·373	0·752
50·6 ,, ..	0·386	0·344	0·598
50·7 ,, ..	0·315	0·412	0·619
56·7 ,, ..	0·376	0·331	0·578
71·0 ,, ..	0·212	0·272	0·411

Each of the eight burns was heat treated continuously as it left the kiln. For the higher C_3S mixes it was necessary to increase the kiln burning temperature and at the same time the treater reheating zone temperature was increased proportionately to maintain a difference of about 70 deg. F.

Table III shows the K_2O, Na_2O_1 and total alkalis as Na_2O in the treated clinker.

TABLE III.

C_3S	K_2O	Na_2O	Total as Na_2O
15·0 per cent. ..	0·537	0·363	0·716
27·0 ,, ..	0·421	0·339	0·616
32·4 ,, ..	0·318	0·332	0·541
32·5 ,, ..	0·508	0·358	0·692
50·6 ,, ..	0·199	0·311	0·442
50·7 ,, ..	0·174	0·263	0·377
56·7 ,, ..	0·193	0·263	0·390
71·0 ,, ..	0·090	0·225	0·315

The interesting feature is the large degree to which K_2O is driven off in the kiln and treater and the lesser degree to which the Na_2O is affected. For a 40 per cent. C_3S mix the K_2O was decreased by 0.39 per cent. from the raw material to kiln

clinker and by 0.16 per cent. during treating, while the Na_2O was decreased by 10 per cent. from the raw material to kiln clinker and by 0.07 per cent. during treating.

Comparing the percentage loss for the Na_2O from raw material to kiln clinker with that of the percentage loss from kiln clinker to treated clinker, it is noted that the treater has nearly the same efficiency as the kilns. The K_2O expulsion is not quite so efficient. However, when the temperature difference between kiln and treater is considered it might even be possible to reverse these efficiencies if the treater temperatures were increased to equal the kiln temperatures. These trial burns were made with a normal degree of treatment.

The results of these eight trials showed a practical method of reducing alkalis. In order to show how close the trials compared with a continuous production of 12,500 tons, the alkali results from the cement bin acceptance tests (42 analyses) were grouped according to C_3S content and the average alkali results for each group are shown in Table IV.

TABLE IV.

C_3S	K_2O	Na_2O	Total as Na_2O
30·2 per cent. ..	0·348	0·315	0·544
33·1 ,, ..	0·366	0·328	0·563
36·5 ,, ..	0·311	0·308	0·516
38·6 ,, ..	0·306	0·299	0·500
40·8 ,, ..	0·276	0·281	0·461

The Na_2O results from the acceptance tests compared very favourably with the Na_2O contents of the clinker-treated trial burns, while the K_2O results were somewhat lower, 0.05 per cent. being the maximum difference between the cement and clinker results.

The greatest difficulty was found in adapting the cooling equipment for a purpose opposite to that for which it was designed. The process proved so successful that production has begun of 33,000 tons of A.S.T.M. Type IV cement, with an alkali limitation of 0.60 per cent. total as Na_2O for the U.S. Bureau of Reclamation. The present equipment does not permit the installation of modern efficient clinker grate coolers, and a water spray is used at the treater discharge to effect sufficient cooling.

Tests On Refractory Mortars.

THE results of tests on twelve brands of refractory mortars are reported in a paper by Mr. R. A. Heindl and W. L. Pendergast and issued by the United States National Bureau of Standards (Research Paper No. 1534). The mortars were studied with respect to sieve analysis, pyrometric cone equivalent, amount of mixing water required, trowelling and drying properties, and strengths after heating at various temperatures. The tendency of the mortars to shrink, crack, and adhere when exposed to high temperatures, both in fusion blocks and in units of three bricks each, was also investigated. The mortars, of the heat-setting type, were supplied by eight manufacturers. One mortar was originally submitted as an air-setting mortar of the dry type but, because it had very little strength after air-setting, it was considered a heat-setting mortar.

Each mortar was mechanically mixed with water for one hour, during which period the water content was adjusted to obtain the proper consistency for trowelling. After soaking the mortars overnight they were mixed for an additional four hours before testing. All the tests were made on mortars so treated except the sieve analysis test, which was made after the one-hour mixing. The amount of mixing water was determined by drying samples of approximately 200 gr. to a constant weight of about 105 deg. C.

In the trowelling tests a ¼in. layer of mortar was spread evenly by hand-trowelling on the upper 9in. by 4½in. face of a brick by means of a template. Two tests of trowelling properties were made by reducing this ¼in. layer to ⅛in. in one stroke, and to ⅛in. in 25 strokes (0·005in. per stroke) respectively. The mortar caps were examined before drying for uniformity of thickness and adherence to the brick and, after drying, for cracks. The transverse strength was determined on mortar bars 6in. by 1in. by ¼in. after drying for 27 hours at approximately 105 deg. C. The bars were placed on supports 5in. apart and loaded at midspan. The linear shrinkage determinations were made on three bars of each mortar after heat treatments at 105, 1,350, and 1,500 deg. C. Tests of the mortars for adherence and observations for shrinkage were made by heating each mortar in a fusion block having a compartment ½in. deep. The heat treatments were identical with those used for the bar specimens.

Assemblies of two half-bricks and mortar were used for determining the strength of brick-to-mortar bond. The bricks were cut parallel to the 2½in. by 4½in. faces into two equal parts. A laboratory screw press was used in bonding the two half-bricks with mortar. Sections of ⅛in. drill rod were used as temporary spacers to obtain uniform thickness of mortar joints. The modulus of rupture of the mortar joint was determined after drying the specimen for 27 hours at about 105 deg. C. The specimens were placed on supports 8in. apart and loaded at midspan. A second type of brick-and-mortar assembly was made, consisting of a pier of two standard-size bricks and two half bricks laid flat to give one vertical joint between the two horizontal joints. Three of these piers were made with a trowelled joint ⅛in. thick. The piers were dried at 105 deg. C. and heated

TABLE I.—PROPERTIES OF HEAT-SETTING REFRACTORY MORTARS.

Mortar	Sieve analysis[1]						Pyrometric cone equivalent	Water content of neat mortar	Flow-table readings	Troweling properties. Spreading and reducing layer—		Drying properties of troweled caps	
	Retained on No. 20	Passed No. 20. Retained on No. 40	Passed No. 40. Retained on No. 60	Passed No. 60. Retained on No. 100	Passed No. 100. Retained on No. 200	Cumulative total not passing No. 200				From ¼ in. to ⅛ in. in 1 stroke	From ¼ in. to ⅛ in. in 25 strokes	Adhered	Cracked
1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Cone*	*Percent*	*Percent*			*Percent*	
J 1	0.0	1.7	16.2	21.0	17.2	56.1	31	25.6	72	Good	Good	100	No.
K 1	.2	1.8	9.3	12.9	14.0	37.2	30-31	36.0	76	do	do	0	Do.
N 1	.0	0.2	4.4	9.9	14.5	29.0	32-33	22.8	82	do	do	95	Do.
O 1	.0	.1	3.3	10.6	15.2	29.2	31-32	25.7	70	do	Poor	35	Do.
P 1	.2	12.2	20.2	16.3	15.7	64.6	31	26.4	75	Fair	Fair	100	Do.
Q 1	.1	0.9	17.2	20.1	19.1	57.4	31-32	32.0	65	Good	Good	100	Do.
R 1	1.9	12.7	21.4	12.1	11.2	59.3	35-36	24.6	77	do	do	95	Do.
S 1	0.1	6.5	20.9	16.1	12.9	56.5	35	22.2	74	do	do	100	Do.
T 1	1.2	8.7	9.0	9.5	9.6	38.0	32	41.5	79	do	Fair	0	Moderately.
U 1	1.5	11.5	9.8	7.7	7.7	38.2	31-32	39.0	57	do	Good	0	Do.
V 1	0.1	2.0	16.5	20.7	15.1	54.4	32	32.2	66	do	do	95	No.
Y 1	2.7	32.1	19.2	5.2	6.5	65.7	27-28	21.2	82	do	do	95	Do.

[1] U. S. Standard Sieve Series.

at 1,350 deg. and 1,500 deg. C., and were examined, when cool, for defects of the mortar cap and mortar joints. The bonding ability of a mortar may be judged by grasping the top brick in a pier made of three bricks as described and lifting it. If the mortar and brick pier remains intact, it can be assumed that the mortar has reasonably good bonding properties.

Sieve Analysis.—The results of the sieve analysis are given in *Table* 1, columns 2 to 7. Less than 1 per cent. was retained on the No. 20 sieve for eight of the mortars. In the case of five of the mortars, over 60 per cent. passed the No. 200 sieve. Mortars *P*1 and *Y*1, on the other hand, had the largest percentage of coarse fractions, only 35 per cent. having passed the No. 200 sieve.

Pyrometric Cone Equivalent.—The pyrometric cone equivalent of the mortars (*Table* 1, column 8) ranged from 27–28 to 35–36. The refractoriness of the mortars was fairly high, since the pyrometric cone equivalent was above 30 in all but one instance.

Mixing Water and Flow-Table Test.—The amounts of water, in terms of percentage of the dry weight of the mortar, used for bringing the mixtures to the proper consistencies for trowelling are given in *Table* 1, column 9. The amount of water ranged from 21·2 to 41·5 per cent. In general, the mortars which contained greater proportions of coarse particles, as indicated by the total percentage retained on the No. 200 sieve, required the least amounts of water for tempering. The two exceptions to this relation are mortars *N*1 and *O*1, which contained the lesser proportions of coarse particles. Both of these mortars showed definite alkaline reaction when tested with 0·2 *N* hydrochloric acid and the deflocculation resulting from this alkalinity no doubt accounted for the low percentages of water required. The other two mortars which gave indications of alkalinity were *P*1 and *R*1. Both contained high percentages of coarse-grained material, in fact, *P*1 led all others in that respect, and hence any deflocculating action which could have been caused by the alkalis present may have been largely nullified.

The results of the flow-table test of the mortars in a trowelling consistency are given in *Table* 1, column 10. The values range from 57 to 82, all but three being between 70 and 82, indicating that the initial consistency of most of the mortars was very nearly the same.

Trowelling.—The trowelling tests gave an indication of the workability of the mortars. In the one-stroke test all mortars except *P*1, which lacked sufficient plasticity, proved satisfactory, but in the 25-stroke test mortars *O*1, *P*1, and *T*1 were the exceptions. Mortar *O*1 was rated "poor" because of excessive stickiness, resulting in its adhering to the trowel and being partially pulled from the brick.

The condition of the mortar caps on the brick, after trowelling and drying, are given in *Table* 1, columns 13 and 14. Mortars *K*1, *T*1, and *U*1 showed no indication of adherence to the brick, and mortar *O*1 adhered only about one-third. The remainder had good adherence. The degree of adherence of the mortar cap, however, was no indication of the bonding property of the mortar when used

in joints. The caps were remarkably free from drying cracks ; only two (*T*1 and *U*1) showed any development of cracks and these were not serious.

In *Table* 2 are given the average transverse strengths of the neat-mortar bars after heating at 105 deg., 1,350 deg. and 1,500 deg. C. In each case three values are given : (1) the average for not less than five bars broken in the inverted position ; (2) a similar average for bars broken in the original position ; and (3) the averages for both positions. The results obtained after heating the bars at 105 deg. C. indicate no significant difference in strength with position of specimen during loading. However, the specimens, after heating at 1,350 deg. and 1,500 deg. C., showed strengths averaging about 18 per cent. greater when tested in the inverted position than when tested in the original position. This relation is the reverse of the findings in tests of air-setting mortars of the wet and dry types.

The average transverse strength of the neat mortars dried at 105 deg. C. ranged from 0 to 290 lb. per square inch, those heated at 1,350 deg. C. from 350

TABLE II.—STRENGTH AND SHRINKAGE AFTER HEATING.

Mortar	Transverse strength [1] (modulus of rupture) of neat-mortar bars after heating at—			Linear shrinkage [2] of neat-mortar bars after heating at—			Transverse strength (modulus of rupture) of two-half-brick-and-mortar assemblage after heating at—	
	105° C	1,350° C	1,500 C°	105° C	1,350° C	1,500° C	1,350° C	1,500° C
	*lb/in.*²	*lb/in.*²	*lb/in.*²	*Percent*	*Percent*	*Percent*	*lb/in.*²	*lb/in.*²
J1	230	1,590	2,765	2.4	1.7	3.0	90	520
	240	1,570	2,365					
	235	1,580	2,565					
K1	210	5,200	3,010	6.9	5.9	4.4	0	0
	200	4,235	2,950					
	205	4,720	2,980					
N1	125	3,885	6,020	4.8	3.5	6.3	0	0
	135	2,625	5,090					
	130	3,220	5,550					
O1	160	4,170	4,750	6.3	4.1	6.4	0	0
	150	3,400	4,330					
	155	3,785	4,540					
P1	165	2,120	3,040	2.5	2.9	5.3	25	300
	175	2,035	2,480					
	170	2,080	2,760					
Q1	160	2,680	4,120	6.2	3.1	5.6	0	365
	150	2,355	2,680					
	155	2,515	3,400					
R1	0	1,205	2,315	0.9	0.8	1.5	180	665
		895	2,180					
		1,050	2,150					
S1	190	1,635	2,990	2.5	1.4	3.1	0	[3] 260
	180	1,780	2,175					
	185	1,710	2,580					
T1	170	2,405	3,115	9.2	3.7	5.1	0	0
	180	2,405	2,730					
	175	2,405	2,920					
U1	300	3,405	3,255	7.7	6.4	7.4	0	145
	290	2,920	2,750					
	290	3,160	3,005					
V1	110	2,075	3,140	6.5	3.2	4.8	0	[3] 85
	95	2,060	4,530					
	105	2,070	3,835					
Y1	190	350	1,755	4.0	1.0	3.9	95	460
	205	345	1,655					
	195	350	1,705					

[1] The 3 values determined for each mortar after having been heated at each of 3 temperatures represent, in the order given, the averages for: (1) 5 specimens broken with the surface that was originally at the top during drying in tension ("inverted position"), (2) 5 specimens with the surface that was originally on the bottom in tension ("original position"), (3) all specimens.

[2] Values tabulated in columns for 1,350° and 1,500° C are burning shrinkages.

[3] Average of 2 specimens.

to 4,720 lb. per square inch, and those heated at 1,500 deg. C. from 1,705 to 5,550 lb. per square inch, all the specimens being cooled to room temperature before testing.

The linear shrinkages of neat mortars resulting from heating at 105 deg., 1,350 deg., and 1,500 deg. C. and cooling are given in *Table* 2. The two mortars (*T*1 and *U*1) which show the highest shrinkages after heating at 105 deg. C., were the only ones which cracked on drying after the trowelling tests.

Mortar and Bricks.—The results of the transverse-strength tests made on assemblies of the two half bricks bonded with mortar are given in *Table* 2. After heating at 1,350 deg. C., eight of the mortars indicated no significant bonding of the end faces of half bricks, as indicated by lack of cross-breaking strength of the brick-and-mortar units. After heating at 1,500 deg. C., however, all but four of the mortars had good adherence or bonding properties, the strengths ranging as high as 665 lb. per square inch. In all cases the lack of strength was due to failure of bonding of the mortar and bricks and not to weakness of the mortar.

The results of the visual examination of the mortars in the joints of the three-brick piers and in the fusion blocks after heating at 105 deg., 1,350 deg., and 1,500 deg. C. are given in *Table* 3. Only those cracks described as " bad " would be considered as affecting the quality of the mortar. Almost without exception the information relative to the shrinkage and cracking of a mortar, whether obtained from examination of a fusion block or of a cap, correlated with that obtained on the joints. The following exceptions may be cited. (1) The shrinkage of *K*1 was less in the joints than in the fusion block or in the cap; (2) the shrinkage of *O*1 in the joints and in the fusion block was less than in the cap with comparable heat treatment; and (3) the appearance of mortar *Q*1 in the joints of the pier and that in the fusion block heated at 1,500 deg. C. did not correlate.

In general, the cracking which occurred in the mortar joints and caps could have been predicted on the basis of selecting from the mortars listed in *Table* 2 those having the highest shrinkage values after drying at 105 deg. C.

The results of the test for judging the bonding ability of the mortars by grasping the top brick of a pier of three bricks bonded with mortar are listed in the last two columns of *Table* 3. All the mortars proved satisfactory in the tests except *K*1 and *N*1. Mortar *K*1 failed in this test after having been heated at 1,350 deg. C., and mortar *N*1 failed both after heating at 1,350 deg. and at 1,500 deg. C.

Summary.—The mortars were finely ground as supplied; only one contained as much as 2 per cent. of material that would not pass a United States Standard Sieve No. 20. The refractoriness of the mortars, as indicated by the pyrometric cone equivalent, was high, all but one being above cone 30. The amount of mixing water ranged from 21·2 to 41·5 per cent. The consistencies of the mortars, however, as indicated by the flow-table test, were, with three exceptions, within a narrow range. The ease of trowelling on bricks, determined mechanically, was considered satisfactory except for one mortar. After trowelling and drying, three mortars failed to adhere to the brick, but cracking was absent in all but two

TABLE III.—REFRACTORY MORTARS IN BRICK PIERS.

Mortar	Appearance of mortar in ¼-in. joints [1] of pier after heating at—			Appearance of mortar in fusion block after heating at—			Condition [2] of ¼-in. cap of mortar after heating at—		Bond in pier satisfactory after heating for 1 hour at—	
	105° C	1,350° C	1,500° C	105° C	1,350° C	1,500° C	105° C	1,350° C	1,350° C	1,500° C
Jl	Good	⊥ and ∥ cracks.	Good	Slight shrinkage	Slight to moderate shrinkage.	Slight shrinkage. No adherence.	Good	Good	Yes	Yes.
Kl	⊥ and ∥ cracks.	Moderate ⊥ and ∥ cracks.	Moderate ⊥ and ∥ cracks.	Moderate shrinkage.	High shrinkage. No adherence.	High shrinkage. No adherence.	Badly cracked. 75% not bonded.	Badly cracked. 80% not bonded.	No	Do.
Nl	do	do	do	Slight shrinkage	Moderate shrinkage	Moderate shrinkage	Slightly cracked.	Slightly cracked.	do	No.
Ol	Moderate ⊥ and ∥ cracks.	do	Bad ⊥ and moderate ∥ cracks.	do	do	do	Badly cracked.	Badly cracked. 25% not bonded.	Yes	Yes.
Pl	Good	Good	Good	Good	Good	Good	Good	Good	do	Do.
Ql	do	do	Bad ⊥ and slight ∥ cracks.	Slight shrinkage	Slight shrinkage	Slight to moderate shrinkage.	do	Slightly cracked. 10% not bonded.	do	Do.
Rl	do	⊥ and ∥ cracks.	Thermal cracks. Fused.	do	do	do	do	Slightly cracked.	do	Do.
Sl	do	Good	Good	do	Slight to moderate shrinkage.	Slight to moderate shrinkage.	do	Good	do	Do.
Tl	Moderate ⊥ and ∥ cracks.	Bad ⊥ and ∥ cracks.	Bad ⊥ and moderate ∥ cracks.	Moderate shrinkage.	High shrinkage. No adherence.	High shrinkage. No adherence.	Badly cracked. 50% not bonded.	Badly cracked. 80% not bonded.	do	Do.
Ul	do	do	do	do	do	do	do	do	do	Do.
Vl	Good	⊥ and ∥ cracks.	⊥ and ∥ cracks.	Slight shrinkage	Moderate shrinkage	Moderate shrinkage	Good	Slightly cracked.	do	Do.
Yl	do	Good	Good	do	Good	Slight shrinkage	do	Slightly cracked. 50% not bonded.	do	Do.

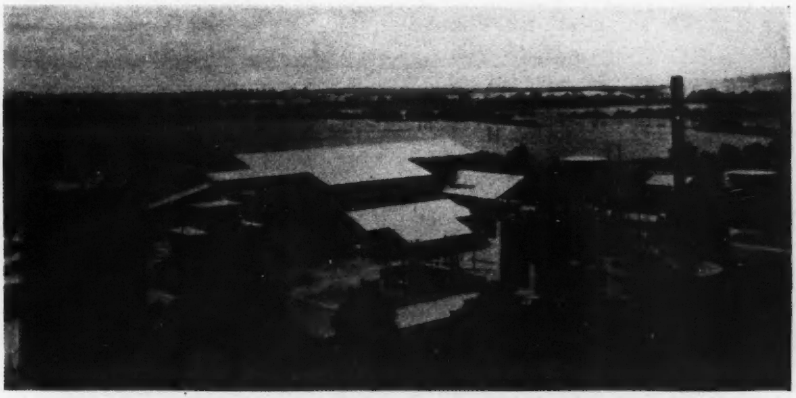
[1] Cracks occurring in the horizontal joints are designated ∥; those in the vertical joints ⊥.
[2] No reference to "adherence" indicates that bonding had taken place between mortar and fusion block.

cases and these were not serious. These two mortars also had the greatest drying shrinkages.

In the transverse tests the bonding strength of the mortars in assemblies of two half bricks and mortar, heated at 1,350 deg. C. and cooled, was poor, as indicated by the lack of any significant strength of eight of the mortars. Satisfactory bonding strength was shown, however, by eight of the mortars after the heat treatment at 1,500 deg. C. On the other hand, when the mortars were tested for their bonding property by grasping the upper brick in a pier made up of three bricks and mortar and lifting it, the results were very different. In these tests only two mortars were observed to fail when heated at 1,350 deg. C., and but one when heated at 1,500 deg. C. and cooled.

New Cement Works in Puerto Rico.

A NEW cement works in Puerto Rico, erected with the financial aid of the United States Government, started production in August last year with a 9-ft. by 180-ft. kiln with a capacity of 200 tons a day. The kiln is equipped with a heat recuperating induced-draught fan system and a grate-type cooler. The grinding installation consists of two new 7-ft. 3-in. by 29-ft. Unidan mills, one for slurry grinding and one for clinker grinding, each driven by a 600 h.p. motor. Limestone is quarried by drilling and blasting and is taken to a 150 h.p. hammer mill. After preliminary crushing, the stone is conveyed by a belt conveyor to storage. Clay is washed in a mill and flows by gravity to two storage basins. The slurry is ground in a 7-ft. 3-in. by 29-ft. Unidan mill. Limestone, sand, and iron ore are weighed and fed to the mill by poidometers. Clay slurry is also added at the inlet of the mill. Pumps deliver the slurry to four 100-ton tanks; after blending and correction it is stored in a basin of 1,100 tons capacity.



New Cement Works in Puerto Rico.

Slurry is fed to the kiln by spiral scoop feeder synchronised with the speed of the kiln motor. The dust chamber is equipped with a tightening device which prevents the admission of atmospheric air to the induced draught system. The kiln is fired with oil. A Fuller-Kinyon pump transports the cement to the packing house.

The capacities of the different units are as follows: Hammer mill, 500 tons per day; slurry mill, 330 tons per day; clinker mill, 260 tons per day; kiln, 200 tons per day. Three 75 h.p. pneumatic compressors provide the air for the slurry basins and for the drills in the quarry.

Because of the large demand for cement in the Caribbean area, it was decided to increase the production of the plant to 470 tons a day, and a Smidth Unax kiln was purchased. The new kiln, which is 9 ft. 2 in. by 8 ft. 2 in. by 9 ft. 2 in. outside diameter and 324 ft. long, is equipped with a ten-unit Unax cooler 3 ft. 5 in. diameter by 18 ft. 4 in. long. The kiln will be equipped with auxiliary equipment, such as spiral scoop slurry feeder with synchronised drive; tightening device between kiln and dust chamber; induced draught fan and louvre damper; oil-firing equipment and primary blower; and central kiln control equipment. The grinding department will be expanded by the installation of an 8 ft. by 36-ft. Unidan mill for clinker grinding. An air separator will be installed in connection with the mill. It is the intention to convert the existing 7 ft. 3 in. by 29 ft. clinker grinding Unidan mill to a slurry grinding Unidan mill when the new clinker grinding mill is installed.

A high-grade limestone is found in several hills some 600 ft. high and covering an area of about 150 acres adjacent to the factory. A deposit of clay of good quality is also available adjacent to the factory. On top of the limestone deposit a very extensive deposit of silica sand of 99 per cent. purity was found, and this is used along with the clay to make the special "206A" cement. Iron ore is brought from a deposit about six miles from the plant. Gypsum was brought from Nova Scotia. The oil consumption with two kilns in operation is 28,000 gallons per day. The oil storage tanks have a capacity of 1,100,000 barrels and there is another storage tank with a capacity of one million gallons at the port of Ponce.

The raw materials have the following analysis:—

	Limestone	Clay	Sand	Iron ore
SiO_2 ..	5·08	53·38	98·12	3·02
AlO_3 ..	1·35	17·99	1·32	3·00
Fe_2O_2 ..	1·58	7·73	0·10	95·05
CaO ..	50·14	2·94	0·14	0·74
MgO ..	0·62	3·71	—	—

A slurry for producing "206" moderate-heat cement can be obtained by proportioning the materials as follows: 85·0 per cent. limestone, 8·6 per cent. sand, 6·0 per cent. clay, 0·4 per cent. iron ore. Standard Portland cement as well as various special cements can be produced by combining the various raw materials.

Soil-Cement Paving.

THE first full-scale experiment in the stabilisation of soil with cement, using agricultural machinery, has recently been carried out in this country. The occasion arose when it was desired to pave a fairly level rectangular ploughed field of about four acres for use as a steel yard. The requirements were to provide with the limited labour available and in the shortest possible time a firm and even surface, capable of bearing wheel loads of up to three tons on pneumatic tyres, for the storage of steel sections up to five tons in weight, and loads generally imposed in the construction of vessels of up to 600 tons displacement. On the advice of the Cement and Concrete Association cement-stabilised-soil paving was adopted, and the work was carried out by the Independent Construction Co., Ltd.

The Site.—The subsoil from 9 in. to 1 ft. below the surface was a sandy clay which was probably unsuitable for this treatment, but since the grading necessary to provide a cross fall of 1 in 150 did not expose this it was possible to provide 6 in. thickness of soil-cement by treating the top soil, which was of a silty nature. The subsoil, except at one corner which required special treatment, was sufficiently firm to enable compaction to be effected by means of an 8-ton roller. The surface soil used for the paving was a fine silty loam varying slightly over the site but all coming within the classification A4 of the American Public Roads Administration, its characteristics being as follows :

	Per cent.
Natural moisture content	13·45
Liquid limit	27·15
Plastic limit	21·80
Plasticity index	5·35
Field moisture equivalent	19·40
Shrinkage limit	22·20
Shrinkage ratio	1·62
Coarse sand (passing No. 7 and retained on No. 52 sieve)	6·90
Total sand (passing No. 7 and retained on No. 200 sieve)	26·99
Silt and clay (passing No. 200 sieve)	65·50
Optimum moisture content	16·00

The maximum density was 108 lb. per cubic foot (Proctor density tests). Owing to the high percentage of fines passing a 200-mesh sieve, from 15 per cent. to 18 per cent. of cement by volume would have been necessary to stabilise this soil, but since a gravel pit supplying 1½ in. down all-in ballast was adjacent it was decided to add one-third of this material to the soil, thereby improving the grading and reducing the fines to nearly 40 per cent., as follows :

	Per cent.
Retained on $\frac{3}{16}$-in. sieve	17·68
Passing $\frac{3}{16}$-in. and retained on No. 7	10·33
Passing No. 7 and retained on No. 36	11·72
Passing No. 36 and retained on No. 200	16·97
Passing No. 200	43·30

The cement content decided on to stabilise this was 12 per cent. by volume which, owing to the experimental nature of the work, was deliberately chosen on the high side. Proctor density tests on the soil-gravel-cement mixture showed that the optimum moisture content was 12·8 per cent. and the maximum density 116 lb. per cu. ft. The improvement in the grading is illustrated by the lowered moisture content necessary for compaction and the increased density.

Plant, Labour, and Supervision.—Since the size of the work was not sufficient to warrant bringing heavy plant from a distance only special units were supplied by the contractor, agricultural implements, the smooth roller, lorries, etc., being hired locally. The gravel was tipped in place from lorries. The water distributor was improvised, and consisted of three 200-gall. ship's water tanks mounted on a 6-ton lorry coupled to and feeding, through a small petrol-driven centrifugal pump, a 14-ft. wide spray-bar fitted at the rear. This apparatus, partly through slowness in filling, proved to be rather on the small side for the work. The labour, apart from supervision, consisted of one foreman, one grader and roller operator, two tractor drivers, and six labourers, and it was possible to pave 1,200 sq. yd. 6 in. deep per 8-hour day; the agricultural equipment, rollers, etc., were in use for only a fraction of the time during which they were hired, and given perhaps one extra tractor and more labour the same equipment could have paved an area up to six times the size.

A small laboratory was established. A drying oven and apparatus for the Proctor density tests were installed, but the only essential apparatus was a chemical balance, primus stove, and a few dishes with which rapid determinations of the moisture content of the soil could be made.

Sequence of Operations.—(*a*) The weeds were raked off with a Yorkshire spiked harrow, turf bordering the site being stripped by hand. Pegs were set giving a cross fall of 1 in 150.

(*b*) The surface was graded with a No. 12 "Caterpillar" grader and given a preliminary treatment with a double-furrow plough, cultivator, and disc harrow, two tractors pulling these implements in turn. Soft spots were consolidated by a few passages of a sheepsfoot roller. About 10,000 sq. yd. were graded and treated in one day.

(*c*) The site was divided into areas of about 1,200 sq. yd. each representing one day's work. Gravel was brought on to the first section, tipped at intervals as required, and spread to an even depth of 2 in. with the grader. It was then thoroughly mixed with the soil by frequent passages of agricultural implements until the soil (apart from the gravel) was pulverised so that 80 per cent. passed a $\frac{3}{16}$-in. sieve.

(*d*) This process continued on the following day over the next section, while a bag of cement to every two square yards was laid on the first section. This proved to be the longest operation, six men taking four hours to double-handle the 600 bags required from the stock pile on to a trailer and thence on to the site. This left insufficient time to complete the process during working hours. Since it was impossible to obtain sufficient labour to spread the cement in two hours, it was

CEMENT MAKING MACHINERY

PATENT SLURRY DESICCATORS. ROTARY KILNS WITH PATENT RECUPERATORS. AIR-SWEPT COAL PLANTS. COMPOUND BALL AND TUBE GRINDING MILLS. COMPLETE CRUSHING PLANTS. ROTARY DRYERS. MIXERS AND AGITATORS, ETC.

The illustration shows three 6′ 6″ dia. × 36′ 0″ long Compound Tube Mills, part of a complete Cement Works in Hong Kong manufactured and erected by:

VICKERS-ARMSTRONGS LIMITED

BARROW-IN-FURNESS

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later decided to risk the possibility of rain and to place the bags of cement directly on to the ground the day before from the supplier's lorries, thereby avoiding double handling and enabling the labour to be steadily employed.

(*e*) Bags were opened, the cement was spread evenly with spike and chain harrows in tandem, and then thoroughly mixed with the soil and gravel by repeated passages of a cultivator and disc harrows until the whole had an even colour to the depth of 6 in.

(*f*) The water content of the soil was determined, and the addition required to bring it up to 12·8 per cent. (plus 2 per cent. evaporation allowance on hot or windy days) was calculated in terms of passages of the distributing lorry. This operation took nearly 40 minutes each trip, including filling, so that with the apparatus available the watering was perhaps the second longest item of the process; although normally less than 5 per cent. of water had to be added this represented over 1,200 square yards more than four trips of the lorry.

(*g*) For the wet mixing the water distributor was followed by the spike harrow, the cultivator, and disc harrow, three or more passages of each being necessary according to the nature of the soil.

(*h*) The sheepsfoot roller was next brought on and the ground rolled until consolidated to a depth of 3 in. The grader was then run over to check the grade, and sheepsfoot rolling continued until the feet penetrated to a depth of only about 1 in. The final passages of the sheepsfoot roller were followed by the spike harrow either in tandem or separately.

(*i*) The ground was rolled with the pneumatic-tyred roller and finished to grade with the 8-ton roller.

(*j*) The work was then covered with damp ashes, spread by the grader, for curing, and watered at intervals next day. The soil by that time had hardened sufficiently to withstand the weight of the 600-gall. distributor without marking, the water running off the surface without any tendency to form mud when rubbed.

At any time after the conclusion of these operations the surface would have been suitable for light or heavy slow-moving traffic, and during the next week greatly increased in strength. Since, however, the surface is intended to withstand not only loading but also attrition due to dragging steel plates and lifting their edges with crowbars, it was decided to protect it with a light tar-spray dressing and chippings.

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